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Title: Accelerator R&D At LANSCE

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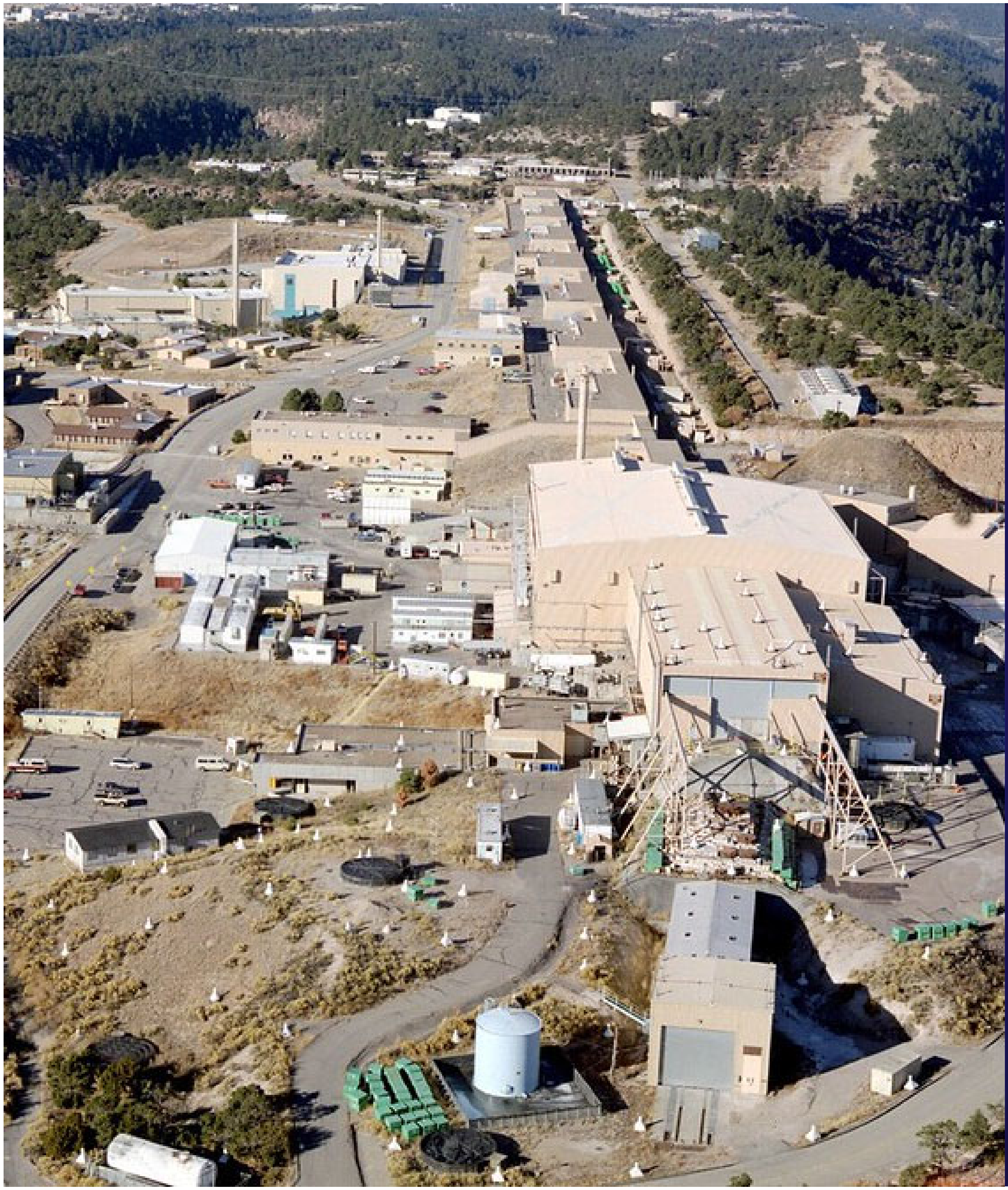

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to protect our nation
and promote world stability

Accelerator R&D At LANSCE

(and beyond)

J.W. Lewellen

29-30 Oct 2019

Los Alamos NATIONAL LABORATORY EST. 1943

NNSA National Nuclear Security Administration

Disclaimers and Thanks To…

- Disclaimers
  - I am not an expert on much of what I will talk about
  - This talk covers the accelerator side, not the user science

- Thanks to: Anna Alexander, Heather Andrews, Petr Anisimov, Yuri Batygin, Jen Bohon, Cynthia Buechler, Greg Dale, Eric Dors, Ilija Draganic, Dmitry Gorelov, Mark Gulley, John Harris (AFRL) Michael Holloway, Frank Krawczyk, Sergey Kurennoy, Jean-Marie Lauenstein (GSFC), Rod McCrady, Nathan Moody, Stephen Milton, Kimberley Nichols, Dinh Nguyen, Vitaly Pavlenko, Louis Peterson, Geoff Reeves, Gary Rouleau, Prabir Roy, Alexander Scheinker, Evgenya Simakov, John Smedley, Tsuyoshi Takima, Charles Taylor, Janardan Upadhyay, Nikolai Yampolsy…

- Collaborations with ANL, BNL, Goddard SFC, LLNL, Physical Sciences Inc., SwissFEL, SLAC, SNS, UCLA….

... And to those not on the above, my apologies for the oversight!

Outline of the Talk

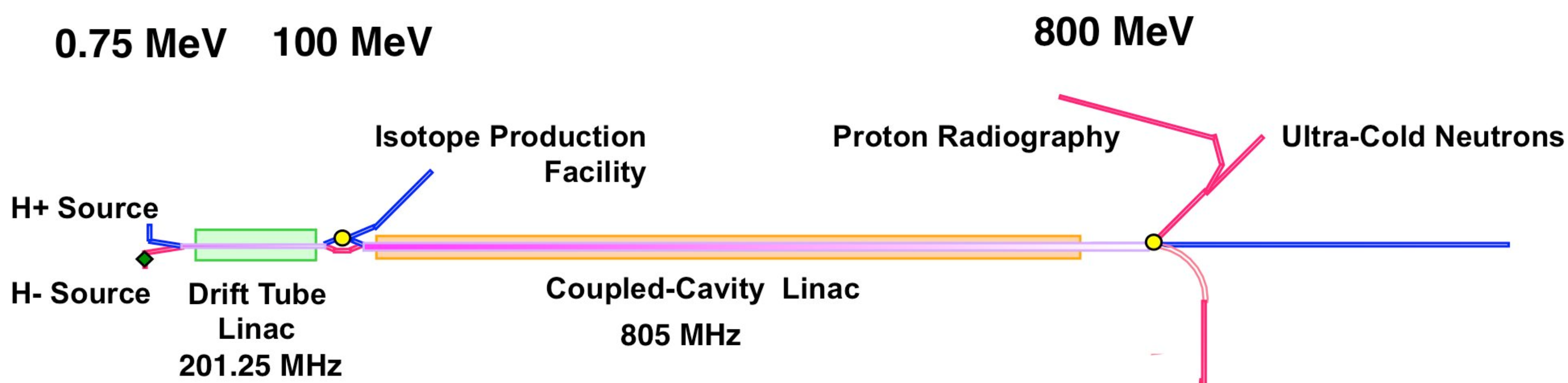
- LANSCE: Present
- LANSCE: Futures (potential)
- Accelerator R&D at LANSCE (and a bit beyond)
  - Optimization & Machine Learning
  - PSR Short-Pulse Generation
  - Ion Source Upgrade, RFQ
  - H^- Photocathode
  - Diamond Cathodes
  - High-Gradient Accelerator Structures
  - SRF Materials
  - X-FELs
  - DARHT and SCORPIUS
  - Accelerators in Space
  - Nuclear Battery
- Conclusions

LANSCE Present

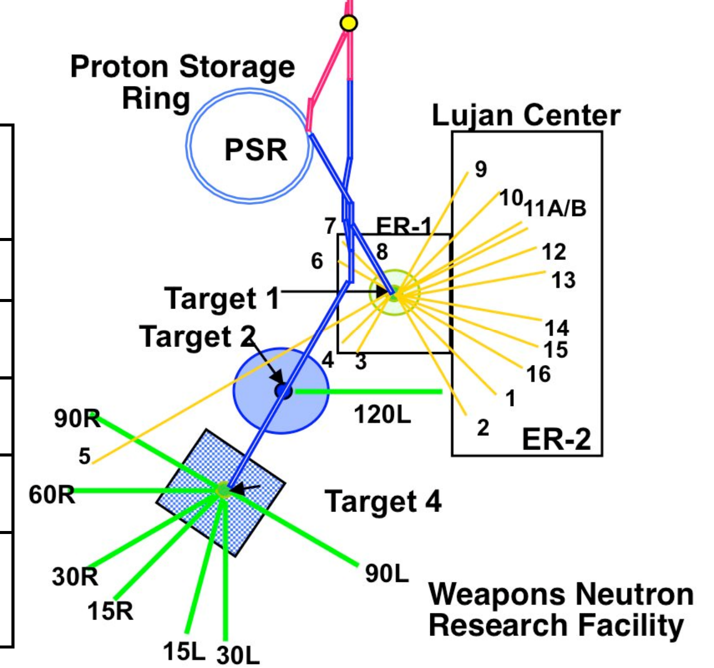
<u>7 “beam termini” – where LANSCE can provide beam</u>

- 3 neutron target stations (Lujan Center, WNR, Ultra-Cold Neutrons)
- 1 proton radiography (pRad) station
- 1 isotope production facility
- 2 “direct beam access” – 800 MeV “Blue Room” and 750 keV H^+

LANSCE Present



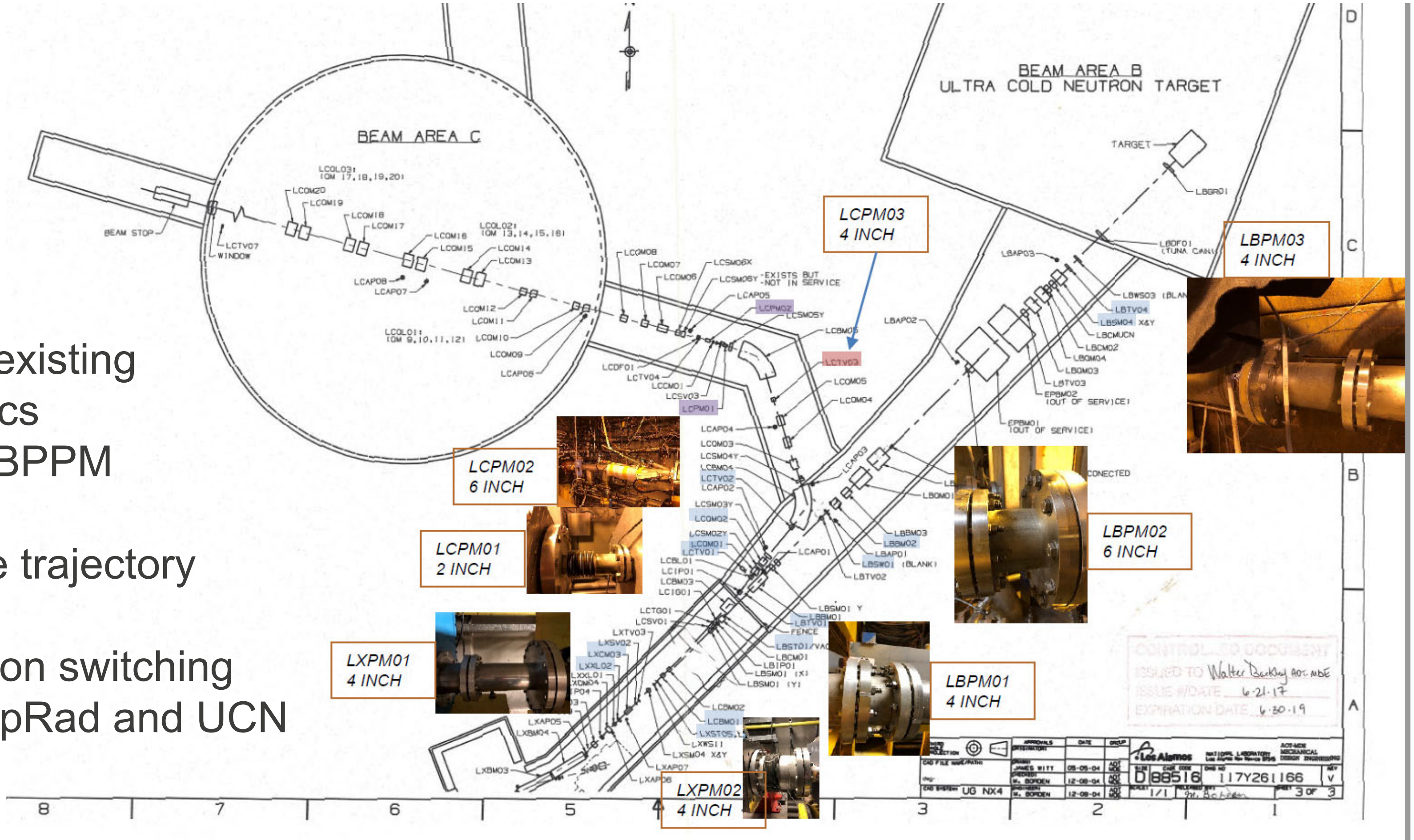
Area	Beam	Rep Rate (Hz)	Chopper	Current /bunch (mA)	Average Current (μA)	Average Power (kW)
Lujan Center	H^-	20	0.8	10	100	80
Isotope Production	H^+	100	1.	4	250	25
Weapons Neutrons	H^-	100	$2.8 \cdot 10^{-3}$	25	4.5	3.6
Proton Radiography	H^-	1	-	10	<1	<1
Ultra-Cold Neutrons	H^-	10 (every 5 sec)	0.8	10	10	8



LANSCE Present: Upgrades

- Broad control-system upgrade – full EPICS implementation
- Targeted diagnostics improvements: pRad and UCN transport lines

- Improve existing diagnostics
- Improve BPPM coverage
- Automate trajectory control
- Fast station switching between pRad and UCN



LANSCE Futures

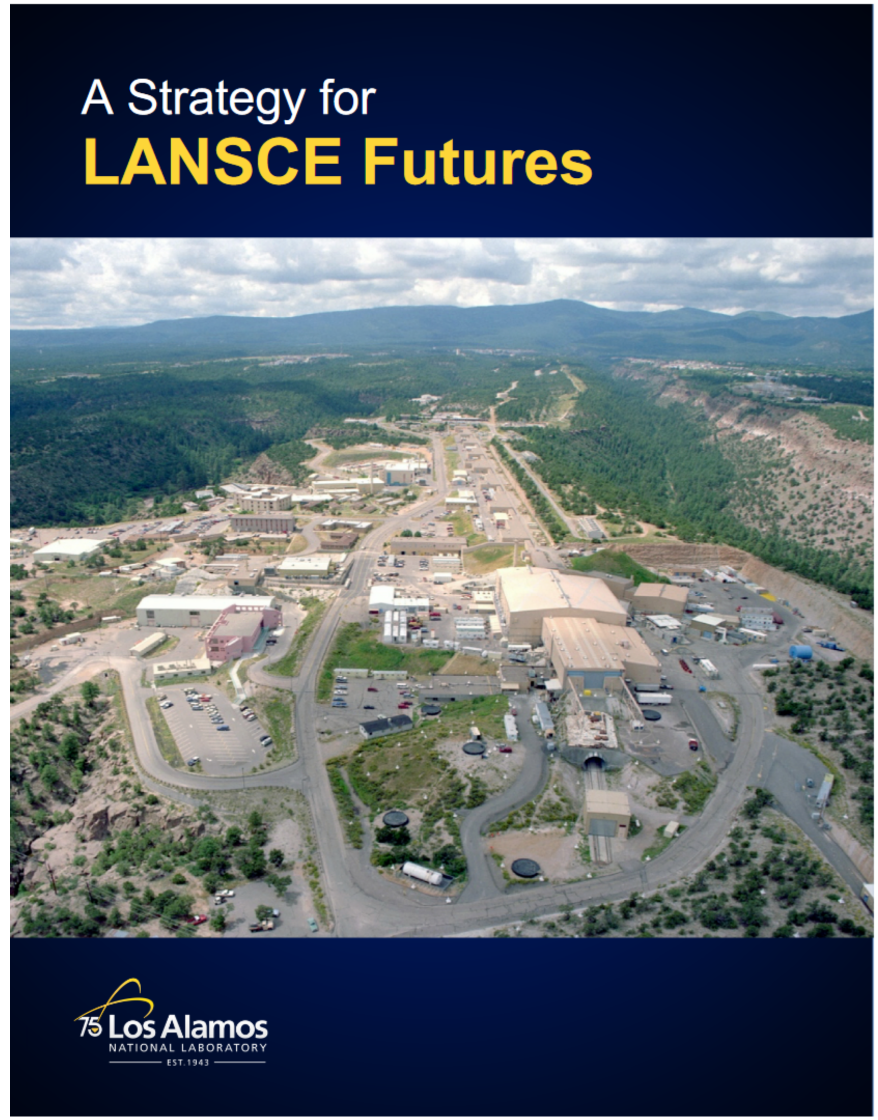
- Broad-brush
  - increased *reliability* and *performance* for existing users
  - additional beam termini for new user communities

Delivered beam: more…

LANSCE Modifications

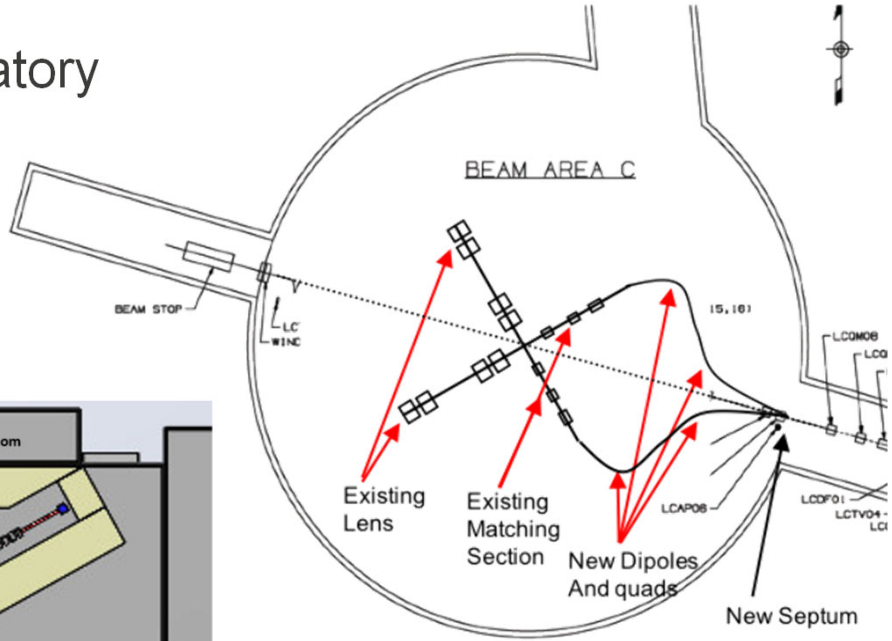
	Power	Energy	Stations	Species[1]
Sources	✓		✓	✓
Structures	✓	✓	✓	✓
Frequency		✓		✓
Beamlines		✓	✓	✓
Species				✓

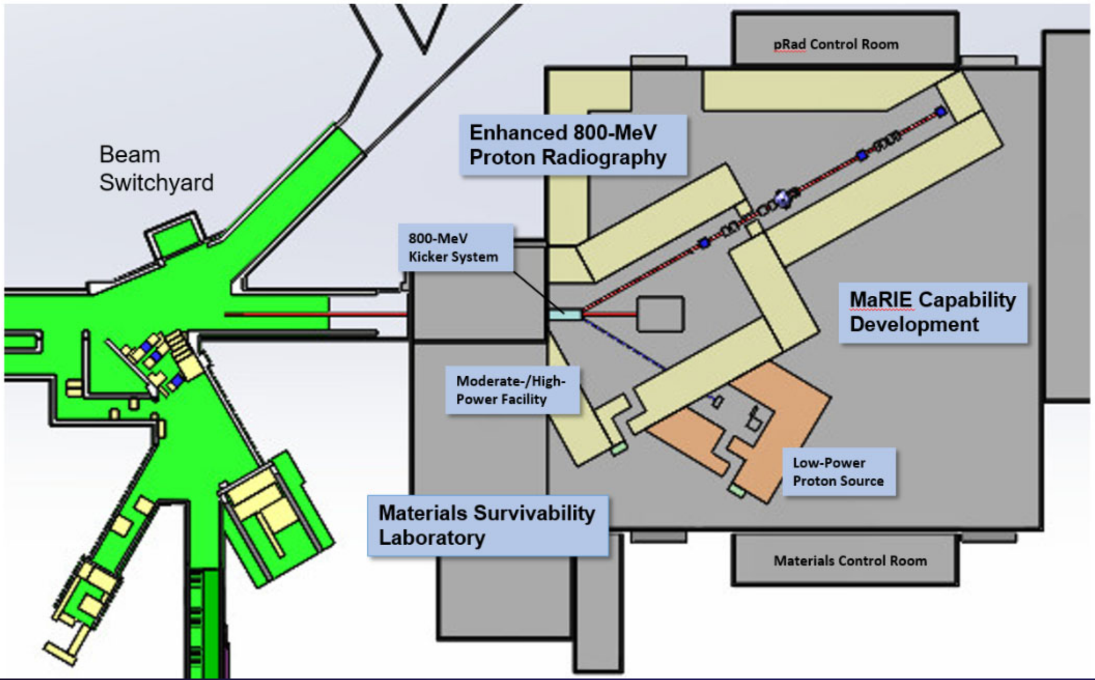
[1] e.g. electrons, photons



LANSCE Futures Deep Dive Identified…

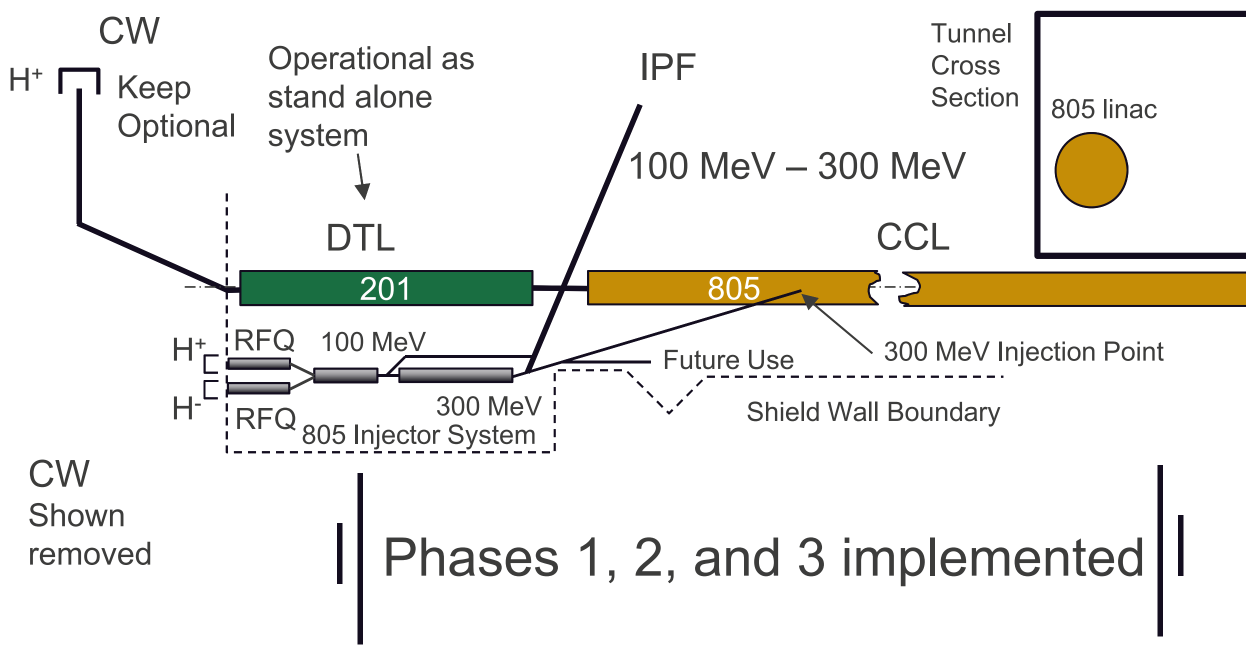
- Dual-Axis pRad
- Area A Materials Survivability Laboratory
  - Space Radiation Facility
  - Enhanced Isotope Production
  - Materials Aging
  - Chromatic Corrected pRad

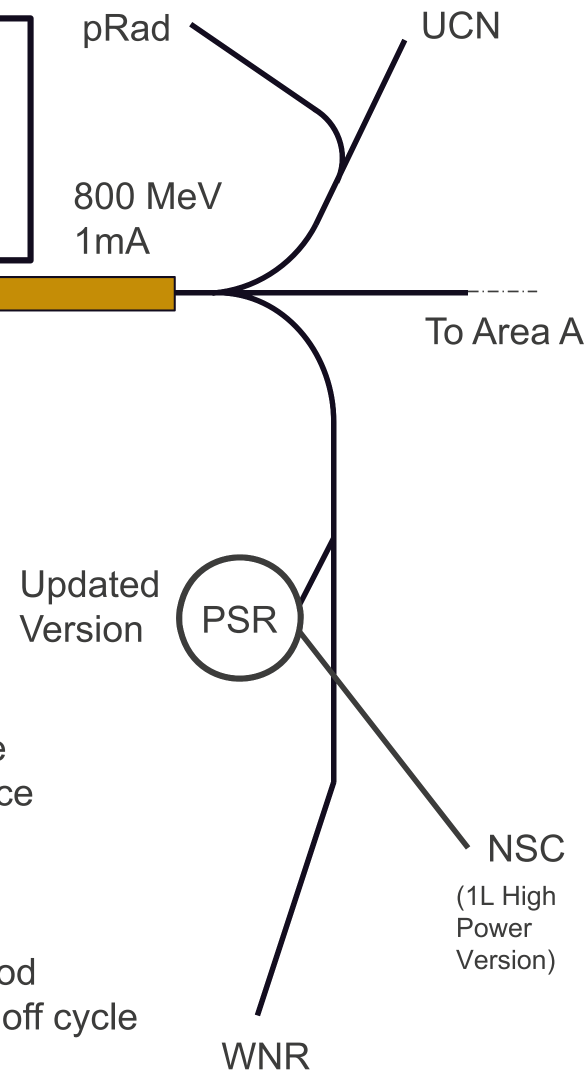




- Improved high energy neutron radiography
- Improved neutron diffraction
- Improved accelerator reliability & performance

A *potential* path…

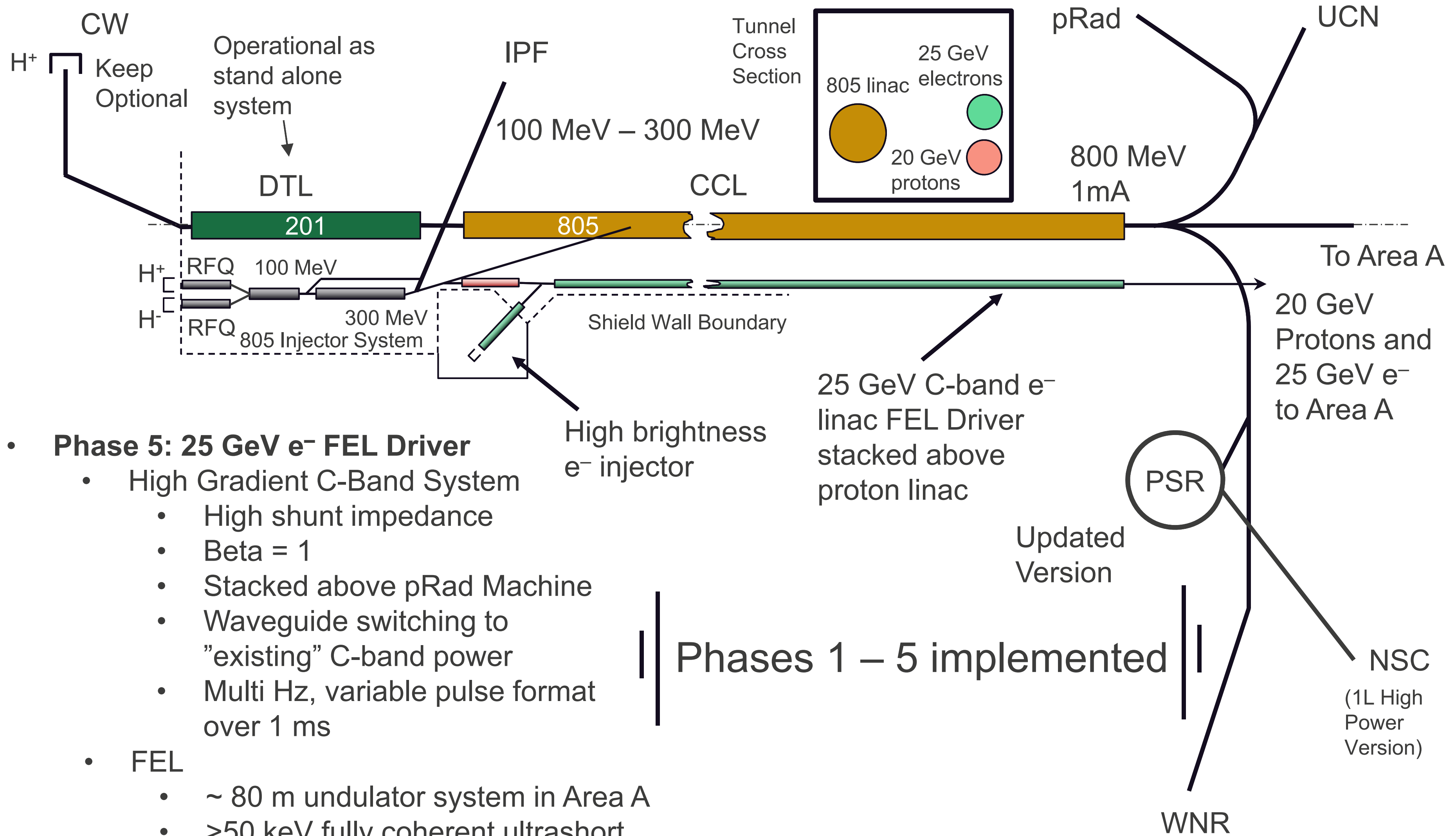




- **Phase 2: Replace CW and DTL**
  - High current H^- and H^+ sources feeding RFQs
  - High gradient 805 MHz Injector
    - Installed adjacent to existing DTL and made functional prior to placing into operation
    - 100 MeV to 300 MeV capable front end system
- **Phase 3: Replace PSR**
  - Large dynamic aperture
  - Large energy acceptance
  - Defined loss point
  - Rapidly serviceable
    - Allows shortening maintenance period
      - 4M on, 2 M off cycle
  - > 3x current capability

Slide courtesy S. Milton

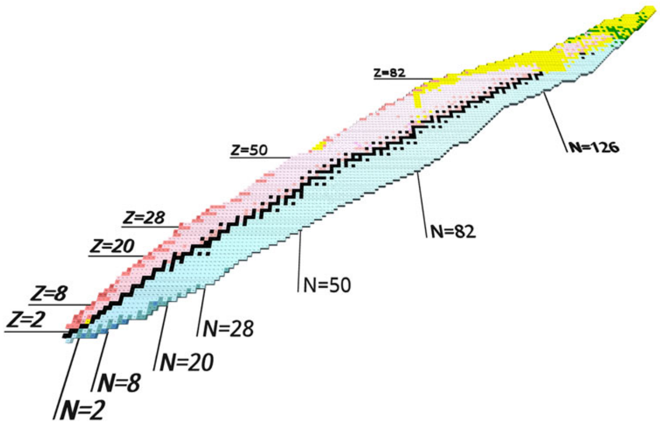
…leading towards…



- **Phase 5: 25 GeV e⁻ FEL Driver**
  - High Gradient C-Band System
    - High shunt impedance
    - Beta = 1
    - Stacked above pRad Machine
    - Waveguide switching to ”existing” C-band power
    - Multi Hz, variable pulse format over 1 ms
  - FEL
    - ~ 80 m undulator system in Area A
    - >50 keV fully coherent ultrashort
    - Building extension required for experimental hall

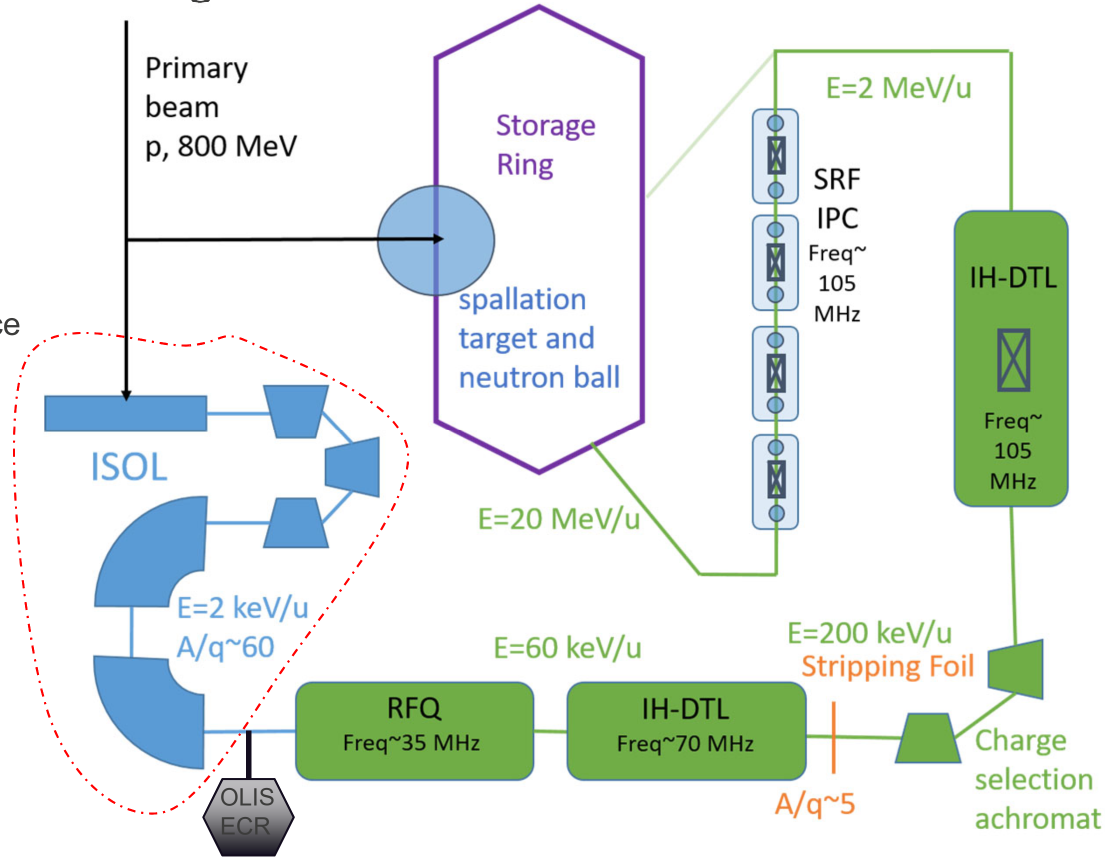
Slide courtesy S. Milton

… and, perhaps, to something like MORD0R



- Nuclear physics goals:
  – Nuclear Reactions for Weapons Science
  – Nuclear structure
  – Astrophysics
  – Material science and other applied physics
- In the range of energies below 2 MeV/u:
  – ^{59}Fe(n,γ)→…
  – Isomers of Ir(n,γ)→…
- In the range ~4-10 MeV/u
  – ^{239}Pu(n,2n)→…
  – $^{87-88}$Y(n,2n)→…
  – Isomers of Ir(n,2n)→…

Neutron Ball allows direct neutron reactions with resulting isotope in exited state even at lower beam energies

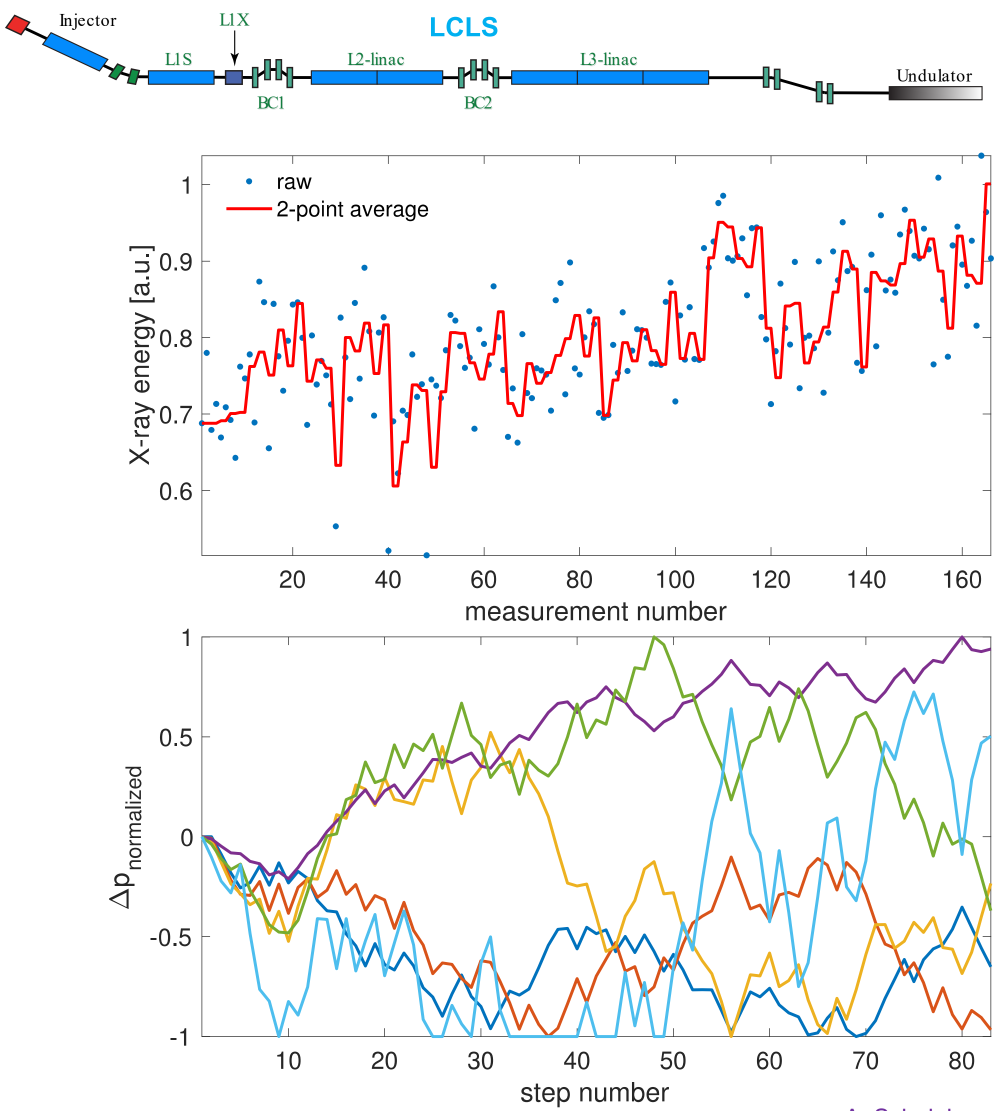


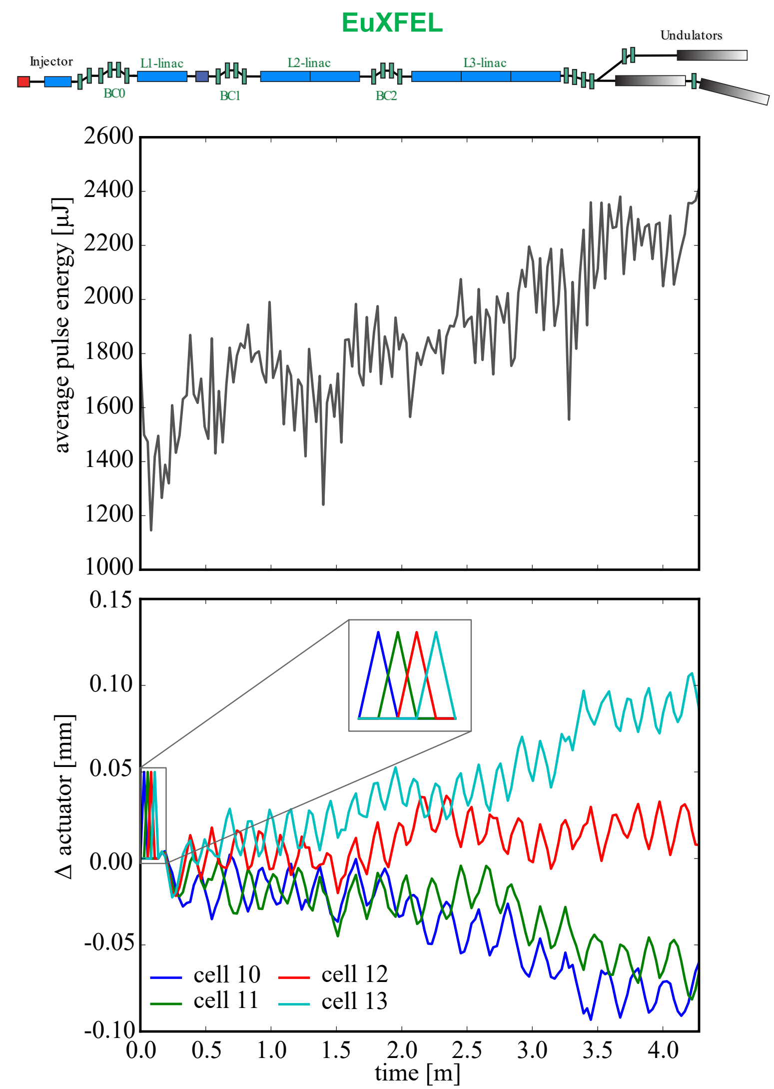
Thanks to Dmitry Gorelov

But, what else is going on at LANSCE?

- Optimization & Machine Learning
- PSR Short-Pulse Generation
- Ion Source Upgrade, RFQ
- H^- Photocathode
- Diamond Cathodes
- High-Gradient Accelerator Structures
- SRF Materials
- X-FELs
- DARHT and SCORPIUS
- Accelerators in Space
- Nuclear Battery

Optimization and Machine Learning: Noisy Systems



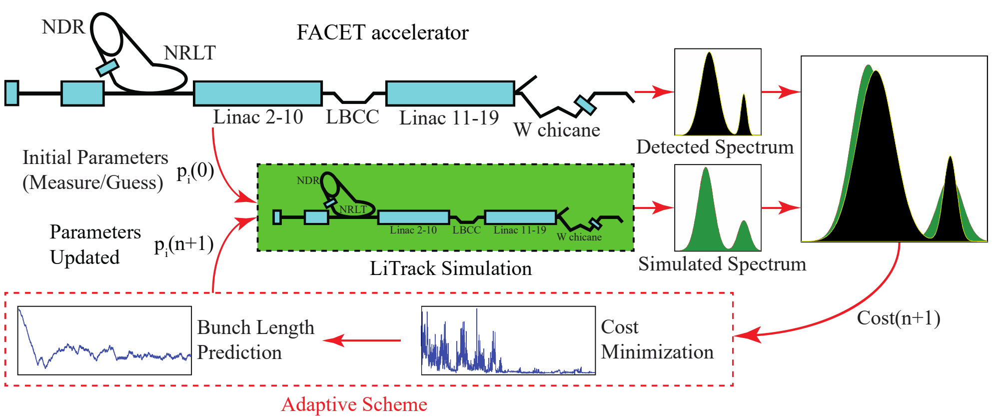


Slide courtesy A. Scheinker

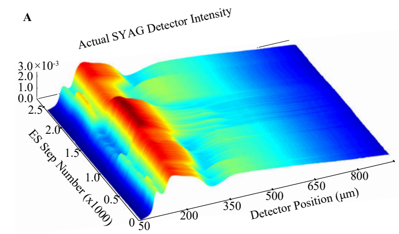
A. Scheinker et al. "Model-independent tuning for maximizing free electron laser pulse energy." *Physical Review Accelerators and Beams* 22.8 (2019): 082802.

Optimization and Machine Learning: Adaptive Model for Non-Invasive Diagnostics

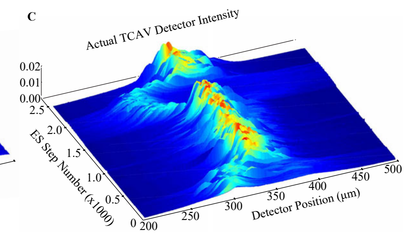
Adaptively tuned simulation using measurements from the machine in an attempt to predict actual beam parameters non-destructively.



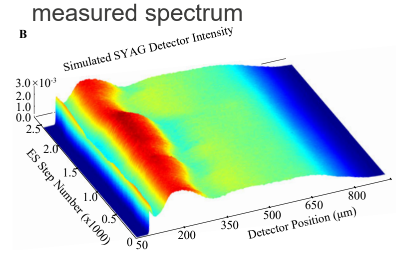
1). Observed energy spread spectrum measurement non-invasively in real time



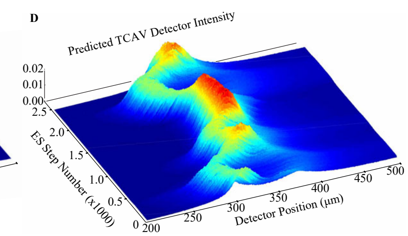
2). Recorded TCAV images during this time and adjusted accelerator settings

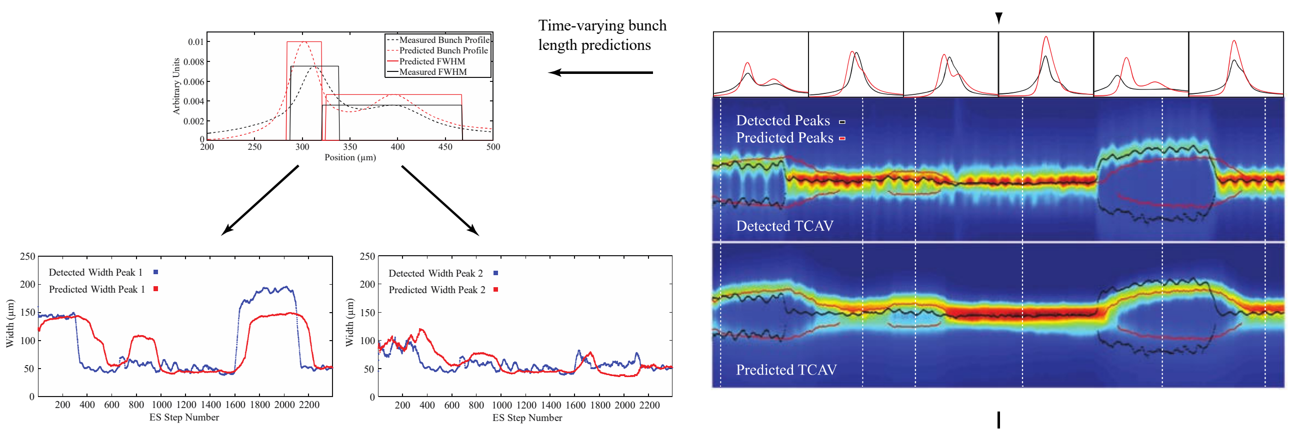


3). Adaptively adjusted model so that simulated spectrum tracked the measured spectrum



4). With this adaptive tuning the model predicted the actual TCAV measurements

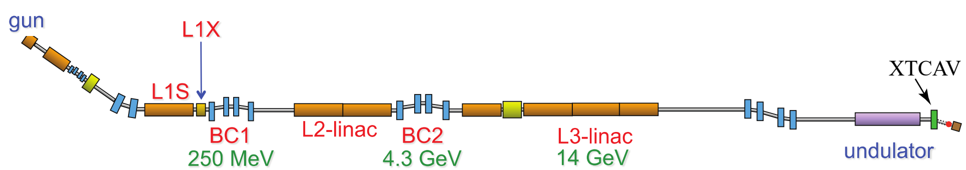




A. Scheinker, et al. "Adaptive method for electron bunch profile prediction." *Physical Review Special Topics-Accelerators and Beams* 18.10 (2015): 102801.

Slide courtesy A. Scheinker

Optimization and Machine Learning: Phase Space Tuning

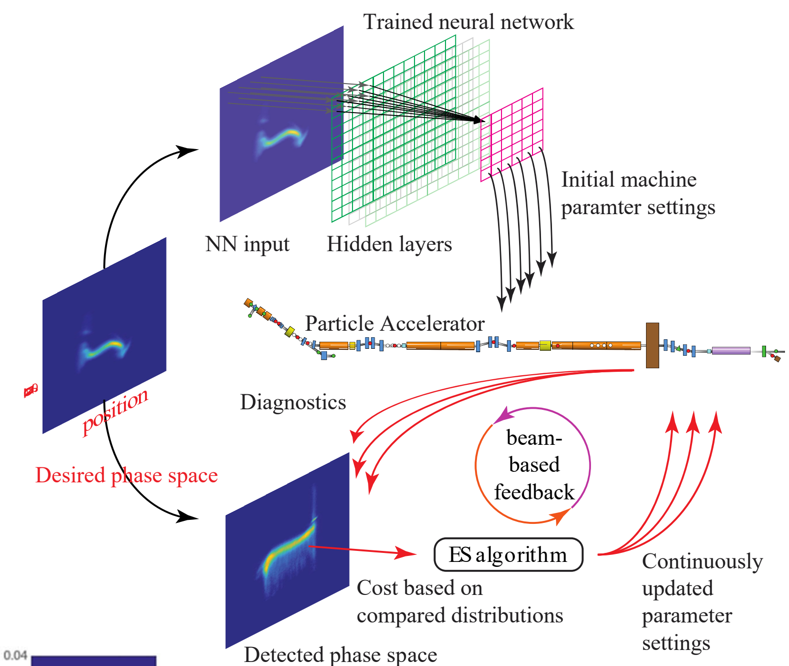


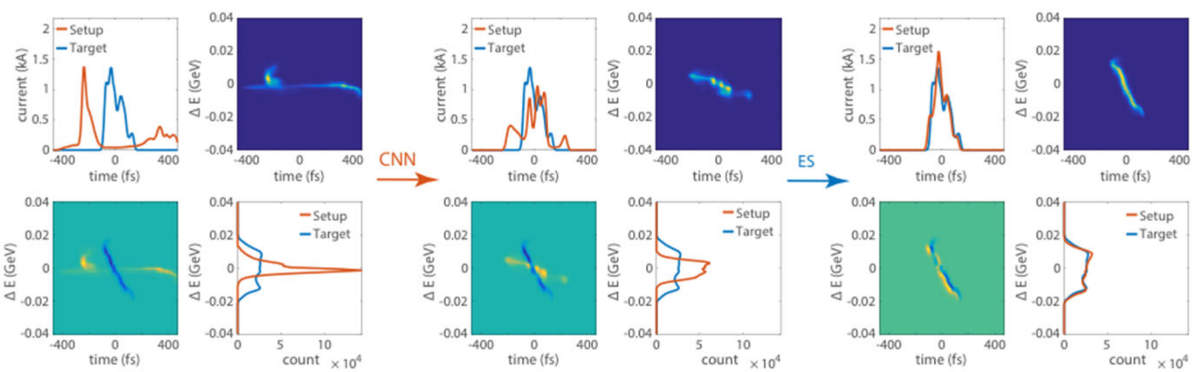
Step 1: Trained a convolutional neural network (CNN) to learn the relationship between longitudinal phase (LPS) space images from a transverse deflecting XTCAV and accelerator RF settings. For a desired LPS the CNN would then give us a guess of what the parameter settings should be.

- CNN prediction not perfect because of interpolation
- CNN prediction limited because the system for which it has been trained changes with time

Step 2: Using the CNN's output as an initial guess, apply model-independent feedback to continuously adjust accelerator parameters to minimize a cost, C, the difference between observed XTCAV image and the desired LPS distribution:

$$C = \int_{-\Delta L}^{\Delta L} \int_{-\Delta E}^{\Delta E} |\hat{\rho}(z,E) - \rho(z,E)|\, dE dz$$

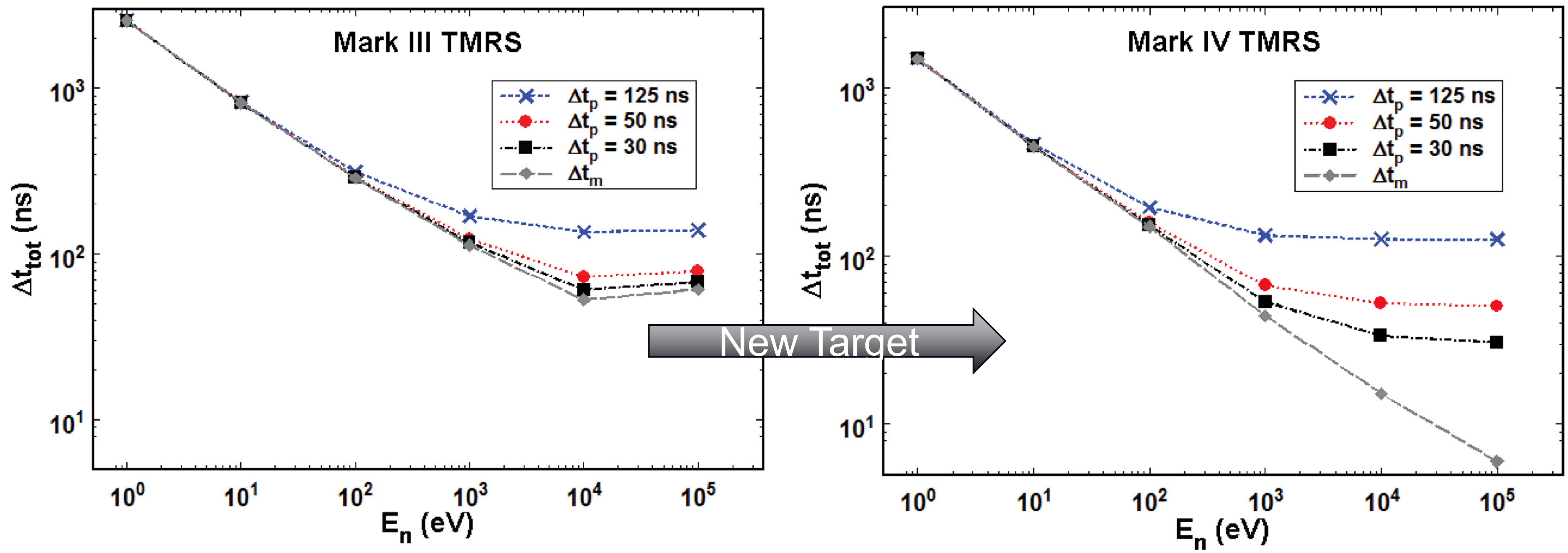




A. Scheinker, et al., "Demonstration of model-independent control of the longitudinal phase space of electron beams in the Linac-coherent light source with Femtosecond resolution," *Physical Review Letters* 121.4 (2018): 044801.

Slide courtesy A. Scheinker

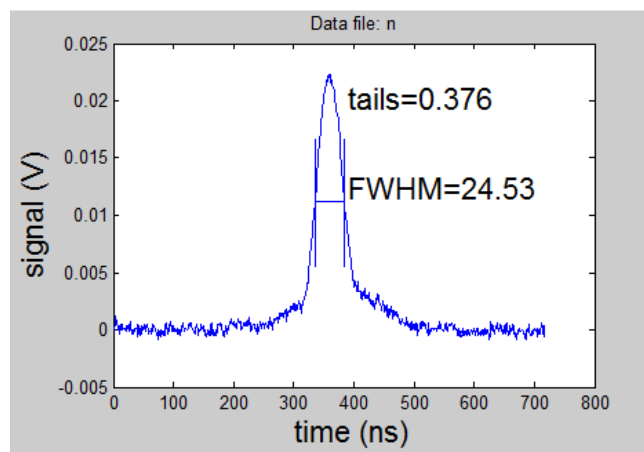
Short-Pulse Generation in the PSR



Presently deliver ~ 300 ns pulses

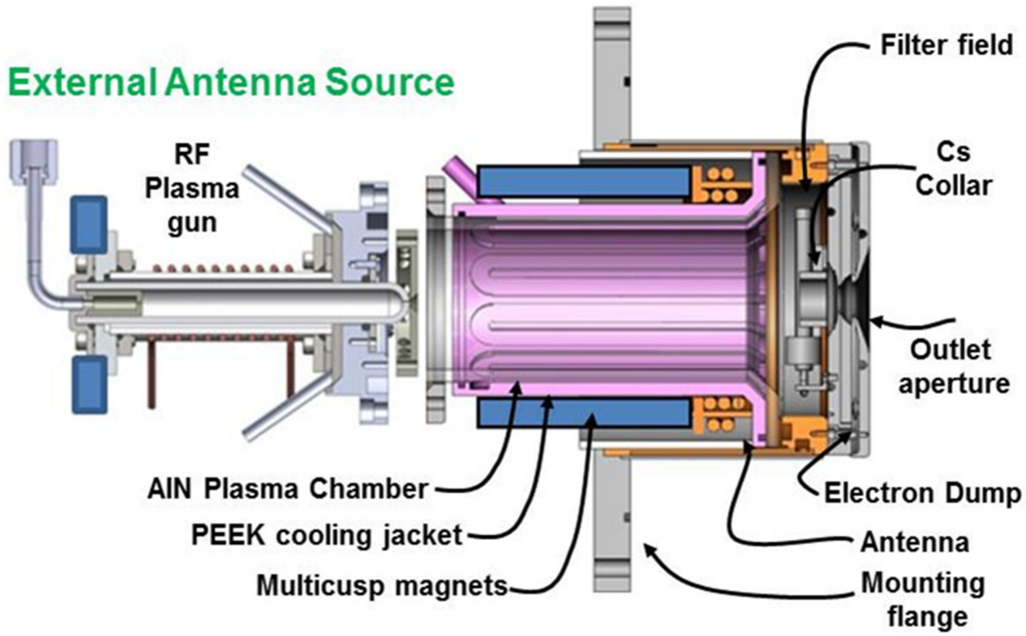
We *can* make shorter pulses …
at the expense of accumulated charge.

Need to understand & improve instability damping, etc.



Thanks to
R. McCrady,
P. Roy, C. Taylor

Ion Source Upgrade: SNS / LANL Collaboration



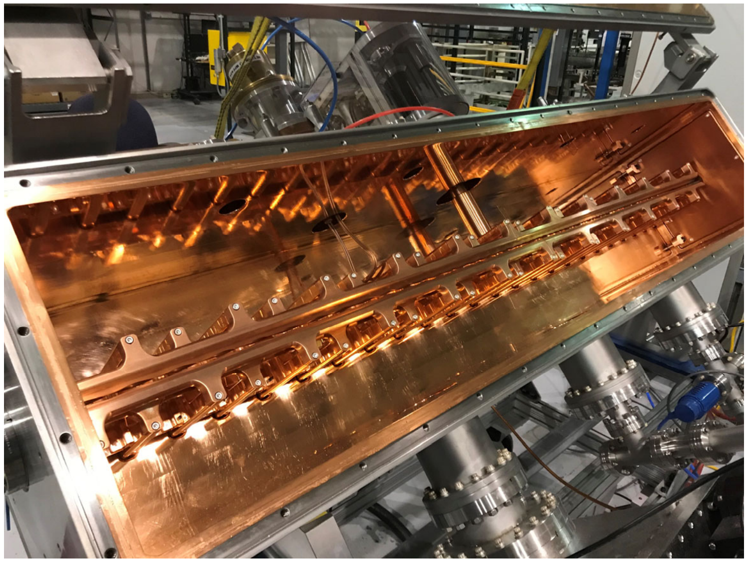
New Design of the SNS RF H- Ion Source
With RF Plasma Gun and External Antenna

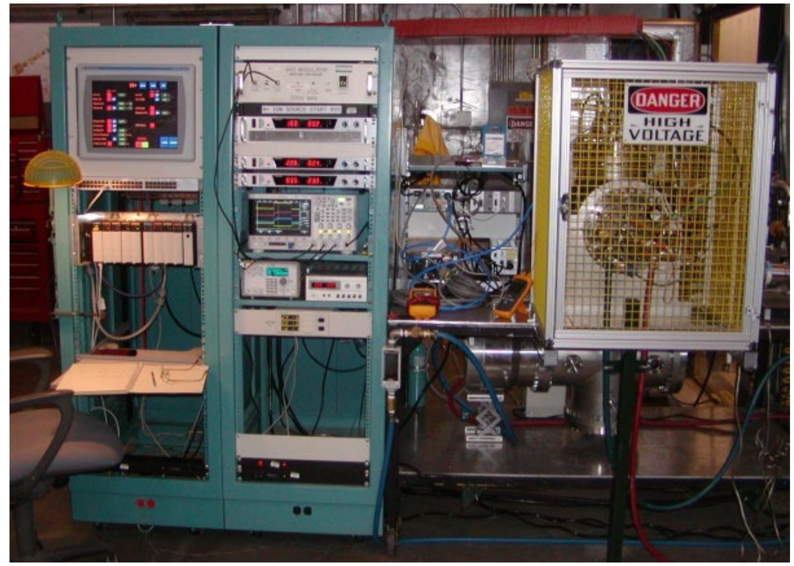
Initial installation: H- Ion Source Test stand
Penultimate home: H- Cockroft-Walton

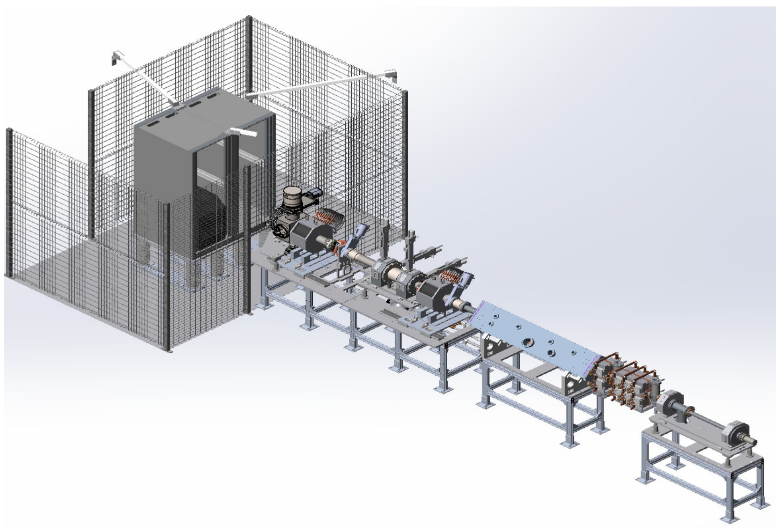
Where we really want to go: New source for complete front-end refresh

Thanks to I. Draganic

RFQ



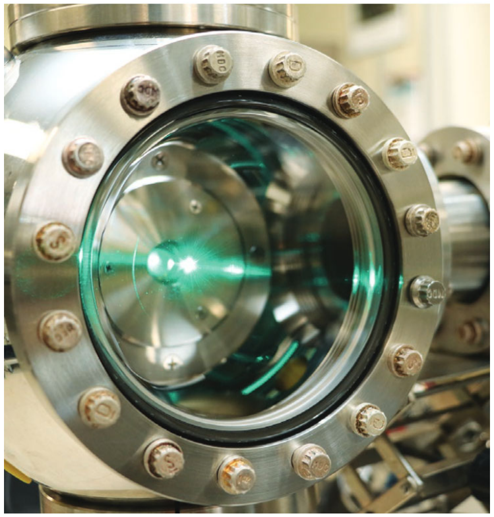




Thanks to I. Draganic,
R. McCrady

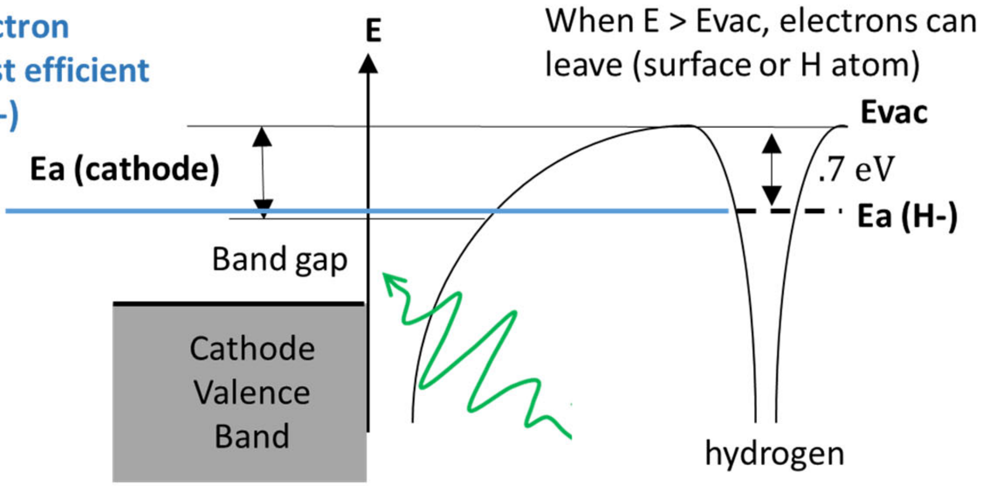
H- Photocathode

- LANSCE source:
  - electron transfer (tunneling) at wall surfaces to produce H-
  - Cs increases efficiency: low barrier, easy for electrons to escape
- Photogated source:
  - Use light to produce electrons at an energy where electron transfer is efficient
  - Similar transfer process, use atomic H beam as H source
  - Potential to enable pulses timed to RF phase, as with electron photoinjector
  - First experiments in progress at ACERT using photocathode chamber



Collisional electron transfer is most efficient when E= Ea (H-)

photogated source uses light+ materials engineering to produce large # of electrons here

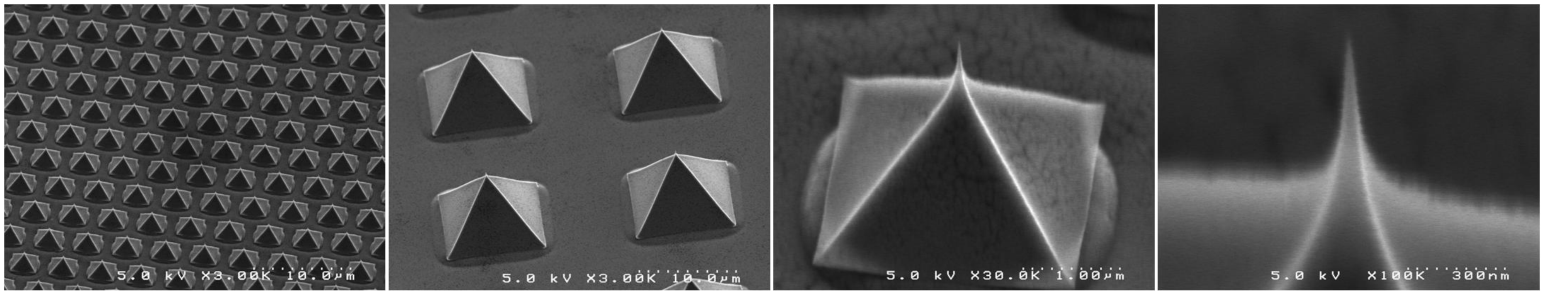


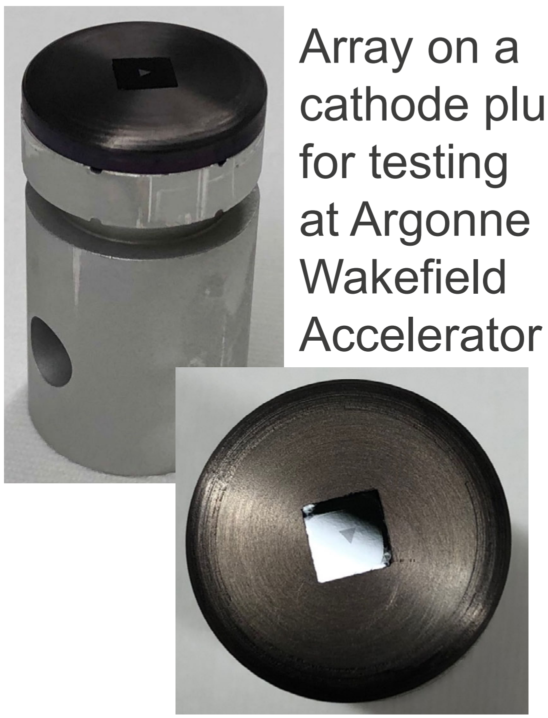
FY20 MFR LDRD

Thanks to A. Alexander, J. Smedley & R. McCrady

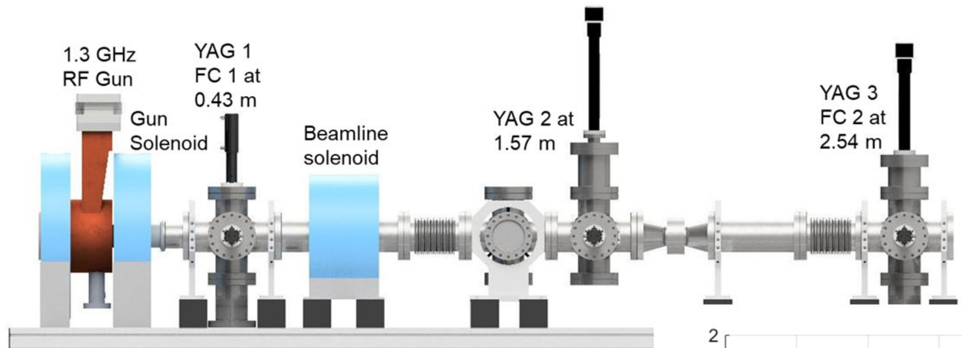
Diamond Cathodes

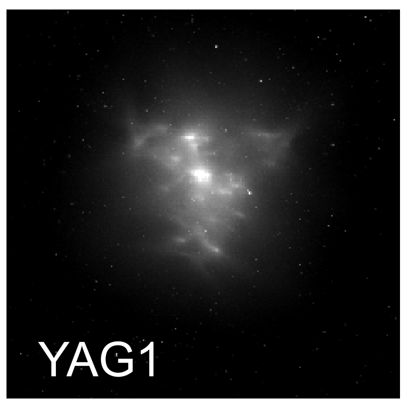
Diamond field-emitter arrays: fabbed with Si wafer technology

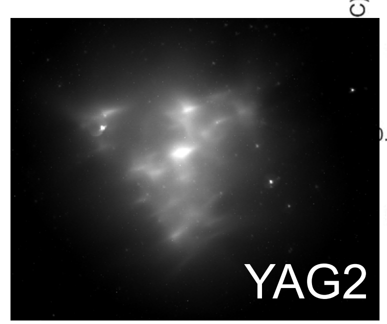


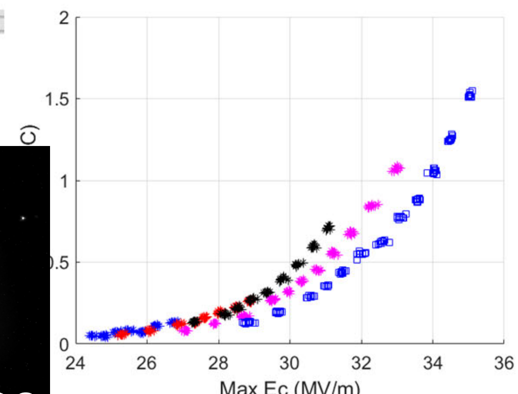


Array on a cathode plug for testing at Argonne Wakefield Accelerator



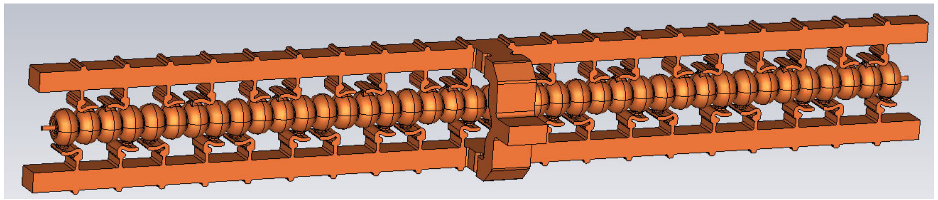






Thanks to K. Nichols, H. Andrews

High-Gradient Accelerator Structures



- Material Science effort
  - better understanding of RF-breakdown
  - Are there better copper alloys with lower RF-breakdown probability?

- RF-structures
  - Design and test reference structures from regular copper (SW, waveguide manifold coupling)
  - Design a test cavity for samples – we try to do more than DC testing
  - Develop experimental capability that includes cryo-cooling with LN

- Advanced manufacturing
  - Implement low-temperature machining, forming, joining and cleaning techniques
  - Fabrication infrastructure: methods that do not compromise the properties of source materials
  - In-house fabrication of newly developed RF-resonators
  - Some basic research into 3D printing with copper – understanding limits, not for production

Courtesy F. Krawczyk

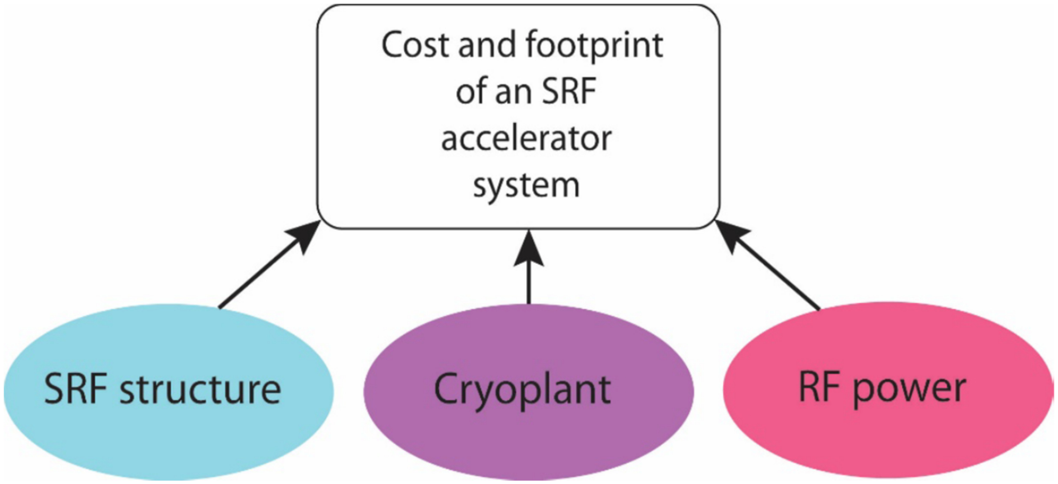
High-Gradient Accelerator Structures

- DDSTE and the ALD for Physical Sciences invested \$1.3M into purchase/installation of a 50 MW peak power klystron
- Klystron supports our 3-year effort for sample and cavity testing, is also seed for an electron beam test accelerator
- Test stand for reduced β and β=1.0 RF-structures

Courtesy F. Krawczyk

Collaborations with SLAC, PSI-SwissFEL, UCLA

SRF Materials



Material	T_c (K)
Nb	9.26
NbTi	10
NbN	16
Nb_3Sn	18.3
Nb_3Ge	23.2
MgB_2	39

2020 MFR LDRD "SRF Cavities: Looking Beyond Niobium"

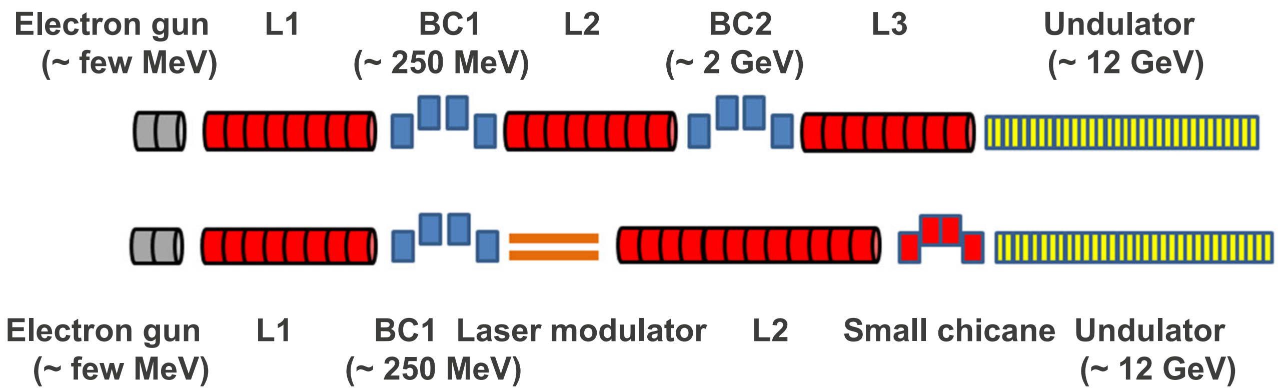
Characterize Nb_3Ge for SRF accelerator application

Coating stand at MST-7

Courtesy E. Simakov, T. Tajima

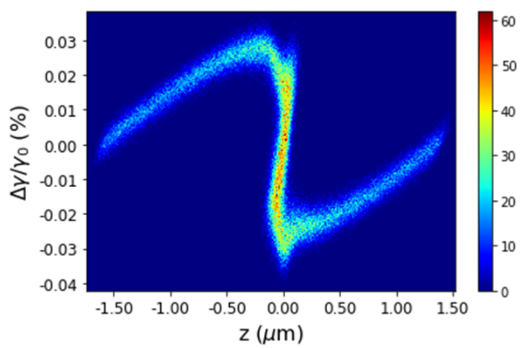
X-FELs

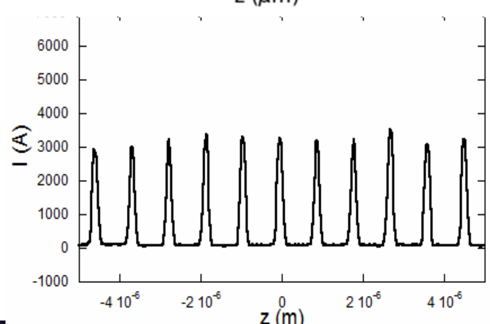
Need: ~3 kA current, 0.1 μm emittance, 0.01% energy spread, at 12 GeV for 42-keV photons



Conventional approach

Laser Assisted Bunch Compression approach





- On-crest RF acceleration makes more efficient use of RF and reduces space charge effects;
- C-band wakes do not seem to hurt but actually help by removing RF curvature;
- 12 GeV bunch compression seems to be possible without significant beam degradation due to CSR and ISR.

Thanks to P. Anisimov & B. Carlsten

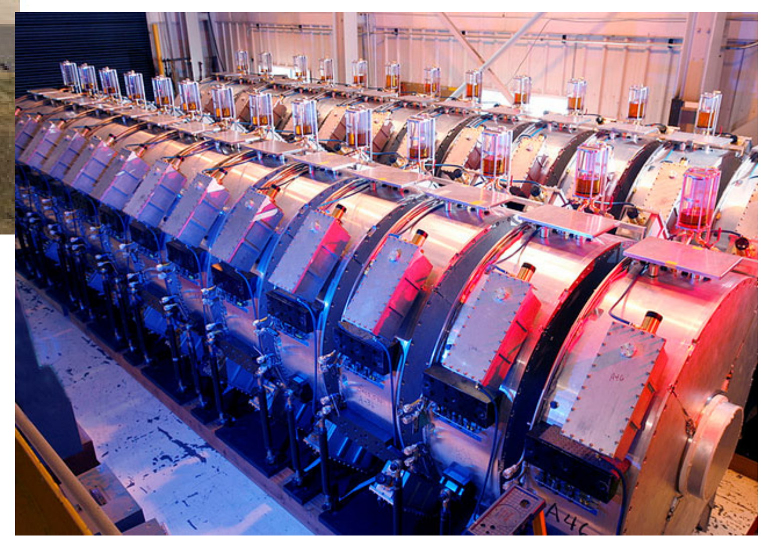
DARHT and SCORPIUS

Linear Induction Accelerators

2-axis radiography

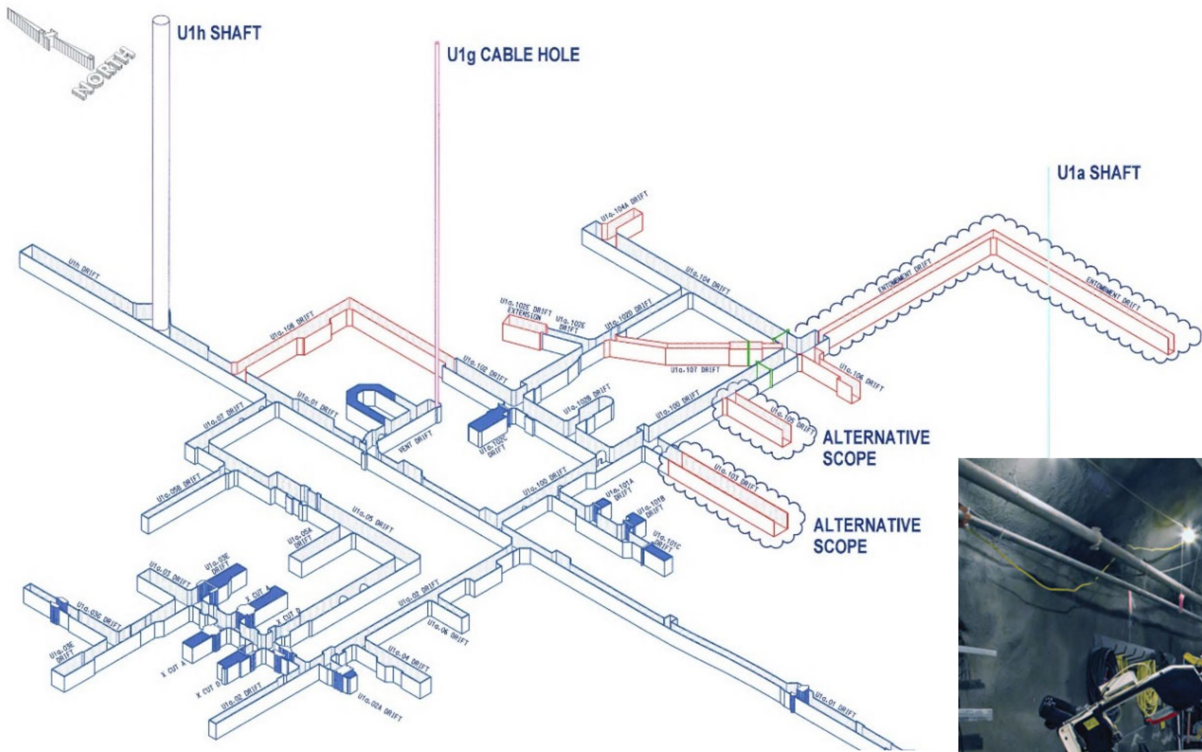
1-2 kA, few hundred ns e^- pulses

15-20 MeV



DARHT and SCORPIUS

- LANL, with LLNL and NSTS, are working to build SCORPIUS and install it in the U1a facility in Nevada … 960 feet underground

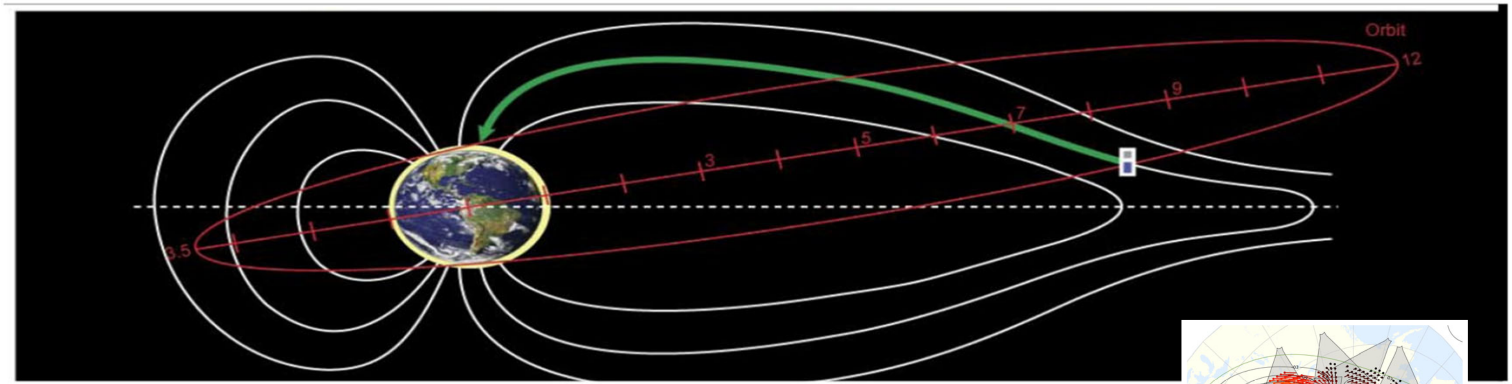


Thanks to G. Dale

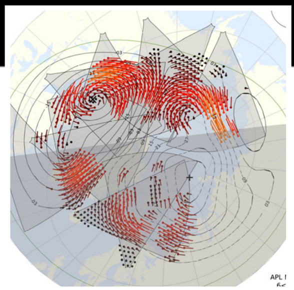
Accelerators in Space

Connections: How are the auroral ionosphere and nightside magnetosphere connected through the time-varying magnetic field?

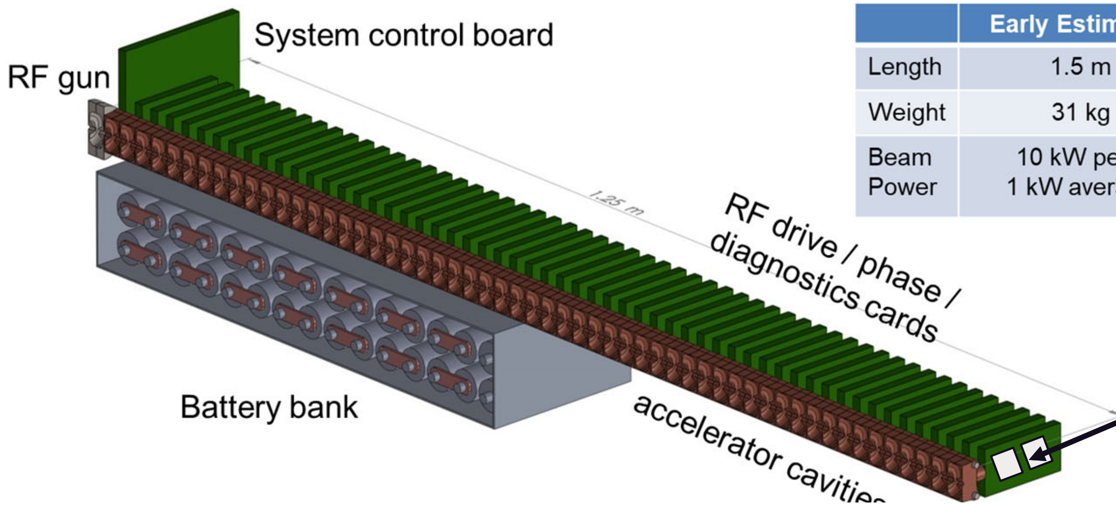
We have magnetosphere *models*, but need better *measurements*.



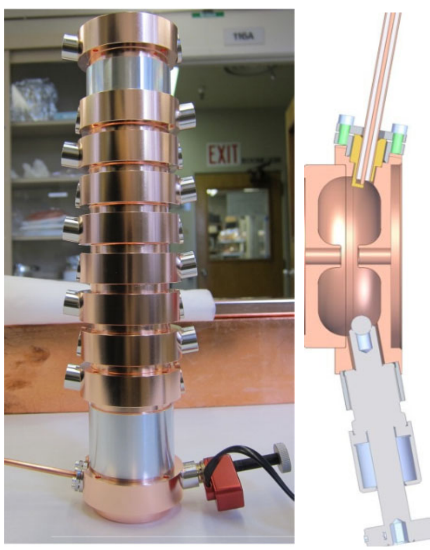
Need ~10 kJ per shot to “light up” artificial aurora

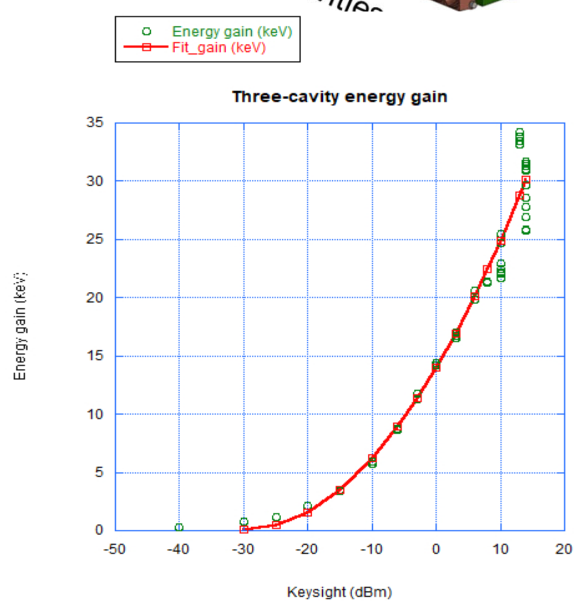


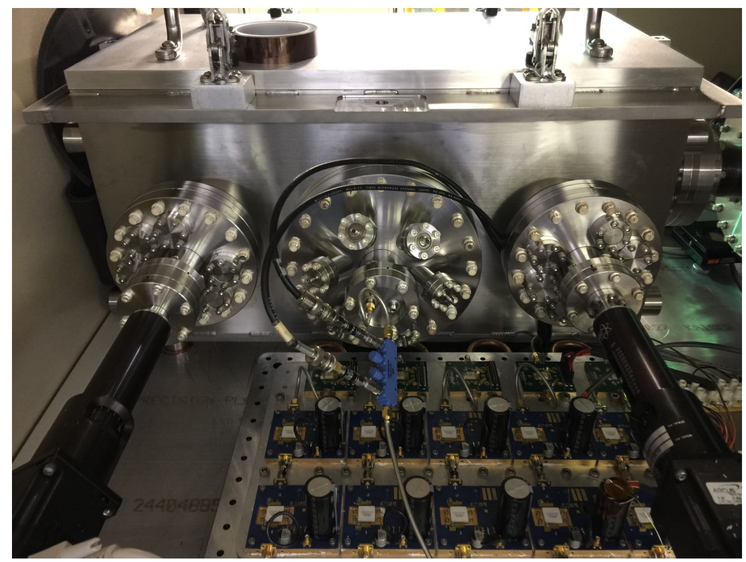
Accelerators in Space



	Early Estimates
Length	1.5 m
Weight	31 kg
Beam Power	10 kW peak 1 kW average





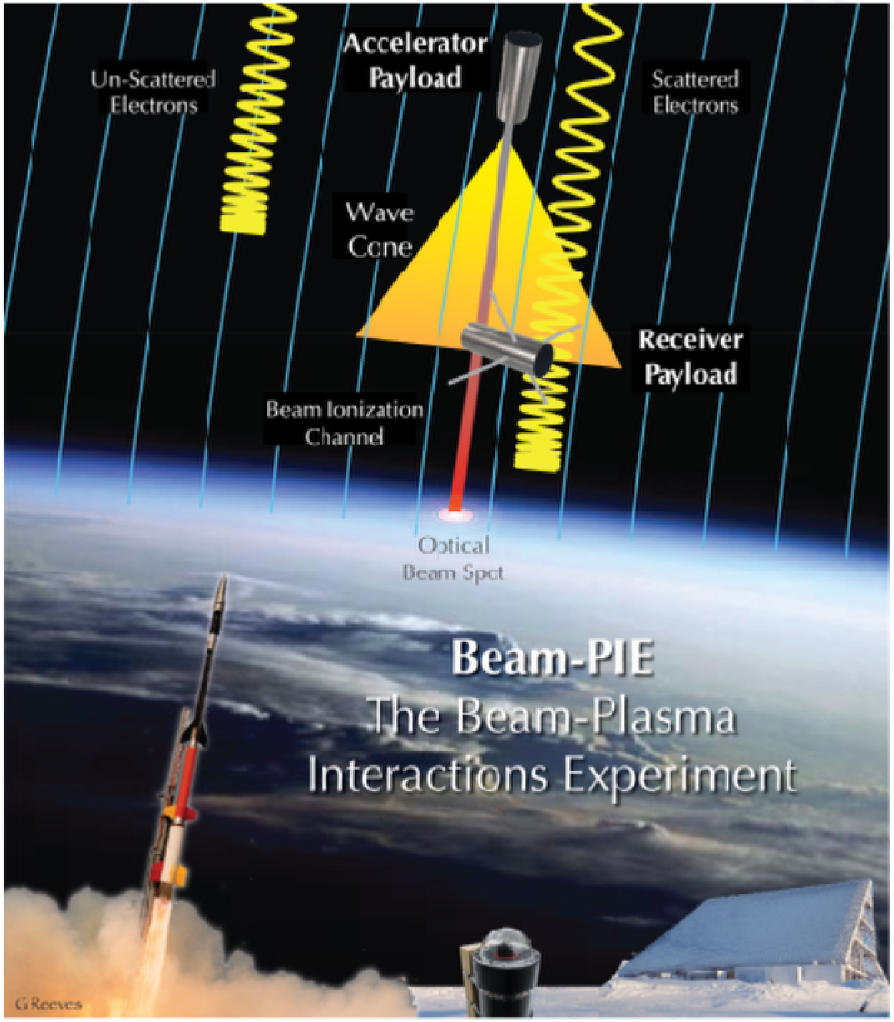


Thanks to D. Nguyen

Beam-PIE

Sounding rocket flight planned for 2020

- Suborbital
- Single cavity, HEMT-driven
- DC electron gun



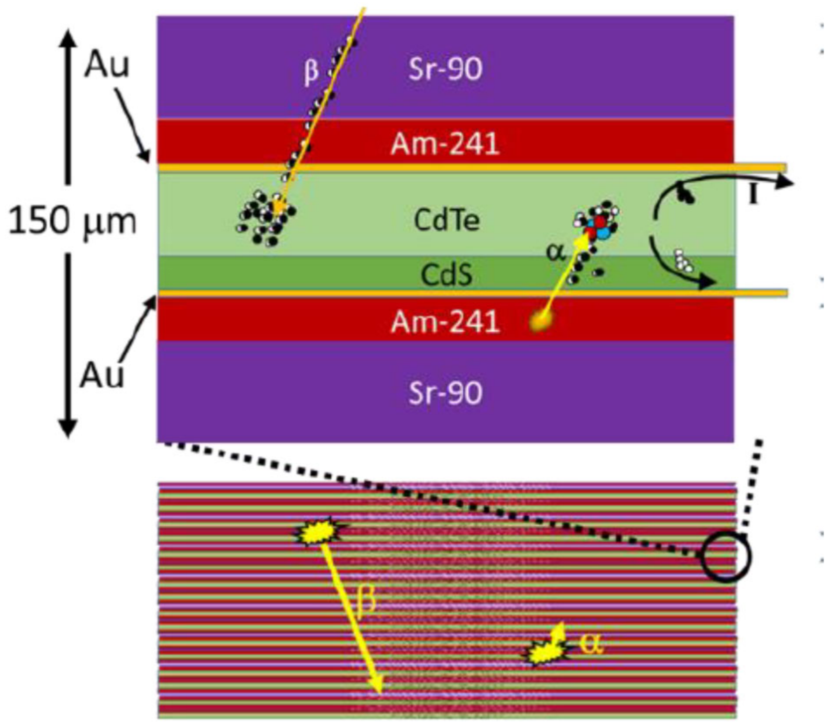
Thanks to B. Carlsten, G. Reeves, E. Dors, M. Holloway

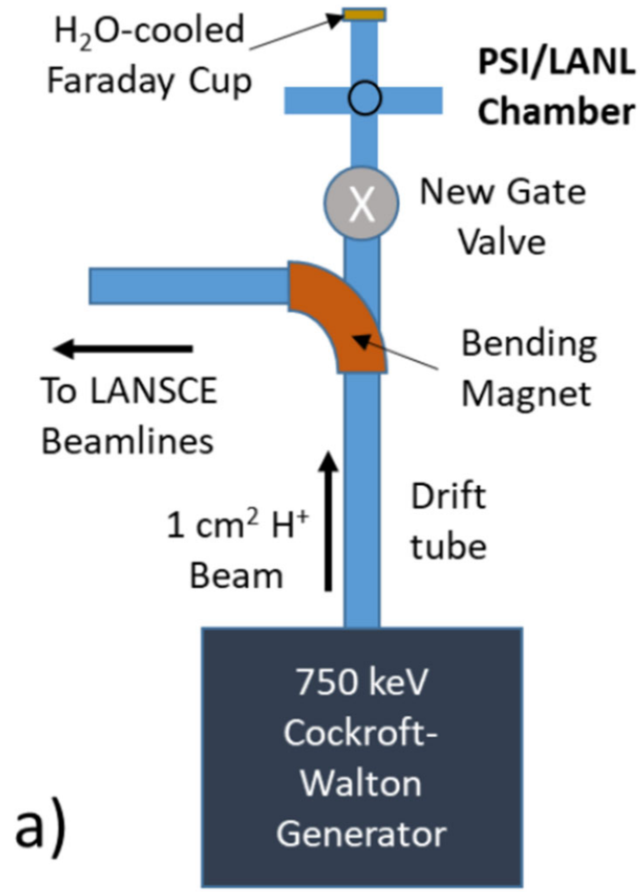
Nuclear Battery Testing (with Physical Sciences Inc.)

Goal: high efficiency, compact energy converter for radioactive material, that is scalable in size

Solution: Layered Photovoltaic/Radioactive material (α or β emitter). Each layer is less than one α range thick, improving efficiency

Unknown: Radiation hardness of PV material versus dislocation damage. Can characterize with proton of similar range (Few MeV α and 0.75 MeV proton both have ~10 μm range.





Slide courtesy J. Smedley

…and that's not everything.

Wrap-Up and Conclusions

- The LANSCE Mesa is a busy place these days
- Upgrade efforts for LANSCE are kicking off
  - “Tank 3 effect” is helping
  - Long-term view: setting up for the next 50 years of operation
- Disparate research activities tie into LANSCE’s future
  - Direct benefit from much of the R&D
  - Enhanced and expanded skillsets brought to the mesa
  - Increased connection with the broader accelerator community